



## Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) Contamination in Surface Soil along Tehran-Semnan Road, Iran

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**ABSTRACT:** The objective of the current research is carrying out the evaluation of the distribution, source, and environmental health risk of polycyclic aromatic hydrocarbons (PAHs) compounds in soil samples taken from the vicinity of Tehran-Semnan road, Iran. This road is a densely populated one in central northern part of Iran with a heavy load of vehicular traffics and several industrial complexes. Four different sampling sites (S1 to S4) were selected in the studied area and then a concentration of 16 PAHs compounds in taken soil samples were measured by High-Performance Liquid Chromatography (HPLC). Total PAHs concentrations varied significantly from 148.4 ng g<sup>-1</sup> to 721 ng g<sup>-1</sup>. The Siman-e Tehran (S1) site has the highest average total PAHs concentrations (654.55 ng g<sup>-1</sup>) and Dehenamak (S4) has the lowest average total PAHs concentrations (168.7 ng g<sup>-1</sup>) among the studied sites. The obtained total PAH concentrations in the studied soil samples are relatively lower than those reported in the literature for similar areas. The diagnostic ratios of fluoranthene to pyrene (Flu/Pyr) and phenanthrene to anthracene (Phe/Ant) were used to determine the petrogenic and pyrogenic sources of PAHs, respectively. The derived results indicated that PAHs contamination in the majority of studied soil samples was caused by both petrogenic and pyrogenic process.

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### 1- Introduction

Polycyclic Aromatic Hydrocarbons (PAHs) are composed of multiple benzene rings with stable structures which are present in the environment for a long period of time [1-4]. Most of PAHs are mutagenic, carcinogenic, teratogenic and also toxic pollutants [5] and thereby the United States Environmental Protection Agency (US EPA) identified 16 of PAHs compounds as priority pollutants (16 PAHs). Seven of PAHs are also classified as probable human carcinogens (7 PAHs) by US EPA because of their carcinogenic potential (Table 1). Natural and anthropogenic sources can introduce PAHs into the environment [6, 7]. PAHs with natural sources are mainly generated through natural events, including fires and volcanic activities [8] while PAHs with anthropogenic sources are mainly generated through incomplete combustion of organic materials during moderate to high temperature (300 to 700°C) processes (pyrogenic sources) [9] as well as moderate temperature (100 to 300°C) processes (petrogenic process) [10, 11]. It should be mentioned that PAHs compounds are mostly generated through anthropogenic activities and the quantities of generated PAHs with anthropogenic sources are significantly influenced by the type of anthropogenic activities [12]. Generally, properties of PAHs are influenced by molecular weight and consequently the number of benzene rings such that those with more than two benzene rings have a relatively low vapor pressure, and also low aqueous solubility (hydrophobic compounds) [13]. Generated PAHs through both natural and anthropogenic

sources in the environment can be easily adsorbed by surface soil particles [13], thereby PAHs are more accumulated in surface soil layers in comparison to other environmental media (water and air) [14, 15]. Therefore, soil can be considered as the main sink of PAHs in the environment [16-18, 12]. Moreover, soil is one of the key natural resources and its contamination by PAHs compounds can have numerous negative impacts on the environment and public health [19]. Thus, the concentrations of PAHs in soil can be considered as an appropriate indicator for determination of local pollution [20, 21]. Concentrations, sources, and environmental risk assessment of PAHs in soils at different areas have been investigated through several studies [22-24, 19]. The road from Tehran to Semnan is located in a central northern part of Iran and has a length of about 216 km. This road is a densely populated road with a heavy load of vehicular traffics which influences enormously the environment of this area. There are also several industrial complexes and companies along Tehran-Semnan road which are important sources of environmental pollutions. Public concern over possible adverse health effects for the population living along Tehran-Semnan road has significantly increased in recent years. Data concerning concentrations of PAHs in soils along Tehran-Semnan road are of prime importance for assessment of the environmental quality of this area. It should be noted that limited studies have investigated soil contamination by PAHs compounds in this area. The main focus of the present study is the assessment of distribution and also identification of potential sources of EPA priority PAHs in soils from four key sampling sites along Tehran-Semnan road in order to

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**Table 1. US EPA 16 Priority Pollutant PAHs and Selected Properties of PAHs**

PAHs compound	Structure (# of rings)	Molecular weight (g/mole)	Solubility (mg/L)	Vapor pressure (mm Hg)
Naphthalene	2	128.17	31	$8.89 \times 10^{-2}$
Acenaphthene	3	154.21	3.8	$3.75 \times 10^{-3}$
Acenaphthylene	3	152.2	16.1	$2.90 \times 10^{-2}$
Anthracene	3	178.23	0.045	$2.55 \times 10^{-5}$
Phenanthrene	3	178.23	1.1	$6.80 \times 10^{-4}$
Fluorene	3	166.22	1.9	$3.24 \times 10^{-3}$
Fluoranthene	4	202.26	0.26	$8.13 \times 10^{-6}$
Benzo (a) anthracene <sup>1</sup>	4	228.29	0.011	$1.54 \times 10^{-7}$
Chrysene	4	228.29	0.0015	$7.80 \times 10^{-9}$
Pyrene	4	202.26	0.132	$4.25 \times 10^{-6}$
Benzo (a) pyrene <sup>1</sup>	5	252.32	0.0038	$4.89 \times 10^{-9}$
Benzo (b) fluoranthene <sup>1</sup>	5	252.32	0.0015	$8.06 \times 10^{-8}$
Benzo (k) fluoranthene <sup>1</sup>	5	252.32	0.0008	$9.59 \times 10^{-11}$
Dibenz (a,h) anthracene <sup>1</sup>	6	278.35	0.0005	$2.10 \times 10^{-11}$
Benzo (g,h,i) perylene	6	276.34	0.00026	$1.00 \times 10^{-10}$
Indeno [1,2,3-cd] pyrene <sup>1</sup>	6	276.34	0.062	$1.40 \times 10^{-10}$

<sup>1</sup>Probable human carcinogens PAHs.

establish a baseline data for PAHs contamination and also evaluation related environmental risk assessment in studied area. A comparison of derived results with data corresponding to the similar studied areas in the literature has also been performed. The presented results in this paper will serve as an important reference data for PAHs in soil along Tehran-Semnan road in order to compare the current results with data obtained in the future.

## 2- Materials and methods

### 2- 1- Sampling procedure

Soil samples were collected during summer 2015 from four sampling sites (S1, S2, S3 and S4) along Tehran-Semnan road for evaluating EPA priority PAHs contamination levels. The locations of sampling sites were selected in order to reflect diverse exposure of soils to potential pollution sources along Tehran-Semnan road. Geographical location of each sampling site was determined by a handheld GPS. The sampling sites locations and specifications are presented in Table 2.

A total of 85 soil samples were analyzed in the current study. Nineteen soil samples were collected from the area within the direct influence (distance less than 5 km) of Siman-e Tehran's plant (S1). Also, twenty-eight soil samples were derived from an area with distance less than 5 km from Nirogah-e Damavand's emissions. Twenty one soil samples were collected from the vicinity of Istgah-e Sorkheh (S3)

which is a gas station and mainly used by motor vehicles for gasoline and diesel recharging. Finally, seventeen soil samples were derived from Dehenamak (S4) which is 15 km away from the area of influence of all the suspected sources of contamination.

Previous studies on soil profile data indicated that PAHs may extend into deep layers of soil but it is expected that more than 90% of the total burden of PAHs is restricted to the surface layer of soil [21, 25]. All soil samples (about 500g) in the current study were collected from the surface layer of soil (0-20 cm) with a stainless steel scoop which was prewashed with methylene chloride and hexane. Each sample was a composite of five subsamples collected from an area of 25 m<sup>2</sup> (5m by 5m) and bulked together to form one sample. All soil samples were transported to the laboratory and were moved in cleaned glass flasks which sealed with aluminum foil lids, in order to prevent sorption by plastic. All soil samples were also air dried for 48 hours at a temperature of 20°C to reach to constant weight and then sieved through a mesh (with an opening size of 2 mm) and stored in the dark at room temperature for a period not more than six months before further characterization.

### 2- 2- Chemical Analysis

The reference standard mixture of 16 PAHs (naphthalene, acenaphthene, acenaphthylene, anthracene, phenanthrene,

**Table 2. Sampling Locations and Specifications of Investigated Sites**

Site	Location		Elevation (m)	Average temperature <sup>1,2</sup> (°C)
	North	East		
Siman e Tehran – S1	35° 34' 22.35"	51° 30' 44.48"	1051	24
Nirogah e Damavand – S2	35° 34' 33.53"	51° 51' 02.10"	1031	25
Istgah e Sorkheh – S3	35° 28' 02.49"	53° 11' 56.37"	1145	31
Dehenamak – S4	35° 21' 52.36"	53° 04' 06.22"	1117	28

<sup>1</sup>Average temperature during summer; <sup>2</sup>Source: Islamic Republic of Iran Meteorological Organization; 3NW: Northwest; 4SE: Southeast; 5W: West; 6E: East; 7SW: Southwest; 8NE: Northeast.

fluorene, fluoranthene, benzo (a) anthracene, chrysene, pyrene, benzo (a) pyrene, benzo (b) fluoranthene, benzo (k) fluoranthene, dibenzo (a, h) anthracene, Benzo (g, h, i) perylene, and indeno (1,2,3-cd) pyrene) was purchased from Macherey-Nagel (Düren, Germany) and diluted in acetonitrile to make desired concentrations. Neutral silica gel (100-200 mesh) and alumina (70-230 mesh) obtained from Sigma-Aldrich (St. Louis, MO, USA) activated, respectively at 130 °C and 250 °C for ten hours and then kept in desiccators before using. Anhydrous sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>) was also heated at 450 °C for four hours and then stored in a sealed container.

The details of the experimental procedures that include extraction, fractionation and PAHs analysis are described comprehensively in Samimi et al. [26]. Briefly, 2 gr of each soil sample was weighed precisely and extracted with dichloromethane (20 ml) in an ultrasonic water bath for 30 minutes. The dichloromethane extract was then filtered through 0.5 µm filter paper and concentrated by a rotary evaporation in 35°C before the cleanup procedure.

The cleanup procedure was performed by a glass chromatographic column (30 cm (L) by 1 cm (ID)) that was packed with anhydrous sodium sulfate in order to absorb any water in the sample extracts, 10 gr of silica gel, and then 4 gr Alumina. The column was also eluted with hexane prior to use. After the introduction of concentrated extract, the aliphatic fraction was collected by elution with 20 ml hexane and then aromatic one was eluted with a 40 ml mixture of hexane/dichloromethane (50:50 v/v). Subsequently, all fractions were evaporated and concentrated with a gentle gas stream of purified nitrogen.

The final concentrated samples were analyzed for PAHs by High-Performance Liquid Chromatography (HPLC) system which was equipped with 410 binary pumps, a 470 scanning fluorescence detector, and a Reodyne 7725i injection loop. The identification of PAHs was performed by comparing individual PAH retention times with those of external reference standards. Quantification was based on the peak areas against external calibration curves for each individual compound.

The pH value of each soil samples was determined. Ten grams of dried soil sample was weighed and dissolved in 20 ml of deionized water. After the continuation of stirring for 30 minutes, the suspension remained for one hour to allow suspended particles to settle out from the suspension and then, pH value was measured by a pH-meter. Organic content of samples was also determined by drying the samples in an oven at a temperature of 440 °C according to ASTM D2974 [27].

### 3- Results and Discussions

#### 3- 1- The concentrations of PAHs in the soil samples

The mean pH value and the organic content of studied samples were 7.96 (from 7.17 to 8.59), and 6.7% (from 3.1 to 11.2%), respectively. The derived results indicated that there is no statistically significant correlation between these variables and total concentrations of 16 PAHs in soils in the current study. The average concentration of the 16 individual PAH analyzed in soils at studied sampling sites were presented in Figures 1 to 4. Figures 1 to 4 show that 16 EPA priority PAHs were present in a majority of soil samples. The average concentrations of total PAHs in soil ranged from 168.7 ng g<sup>-1</sup> (S4) to 654.55 ng g<sup>-1</sup> (S1) with the mean value of 396.33 ng g<sup>-1</sup>.

The obtained results indicated that PAHs concentrations are strongly linked to the land use of each specific site. The S1 has the highest total PAHs concentrations (721 ng g<sup>-1</sup>) and S4 has the lowest total PAHs concentrations (148.4 ng g<sup>-1</sup>) among the studied sites. The average concentrations of total PAHs in soil corresponding to S1 (654.55 ng g<sup>-1</sup>) and S2 (437.68 ng g<sup>-1</sup>) were relatively close together while that found for S3 (324.39 ng g<sup>-1</sup>) was notably lower than those of S1 and S2 sites and close to total PAHs concentration of S4 (168.7 ng g<sup>-1</sup>).

The type of combustion processes [28] and proximity to roads of particular manufacturing [29, 30] have been pointed out as two of the most important factors which can affect PAHs concentrations in soils in the vicinity area. Due to the particular combustion processes and location of S1 which is near to the heavy traffic loaded Tehran-Semnan road,

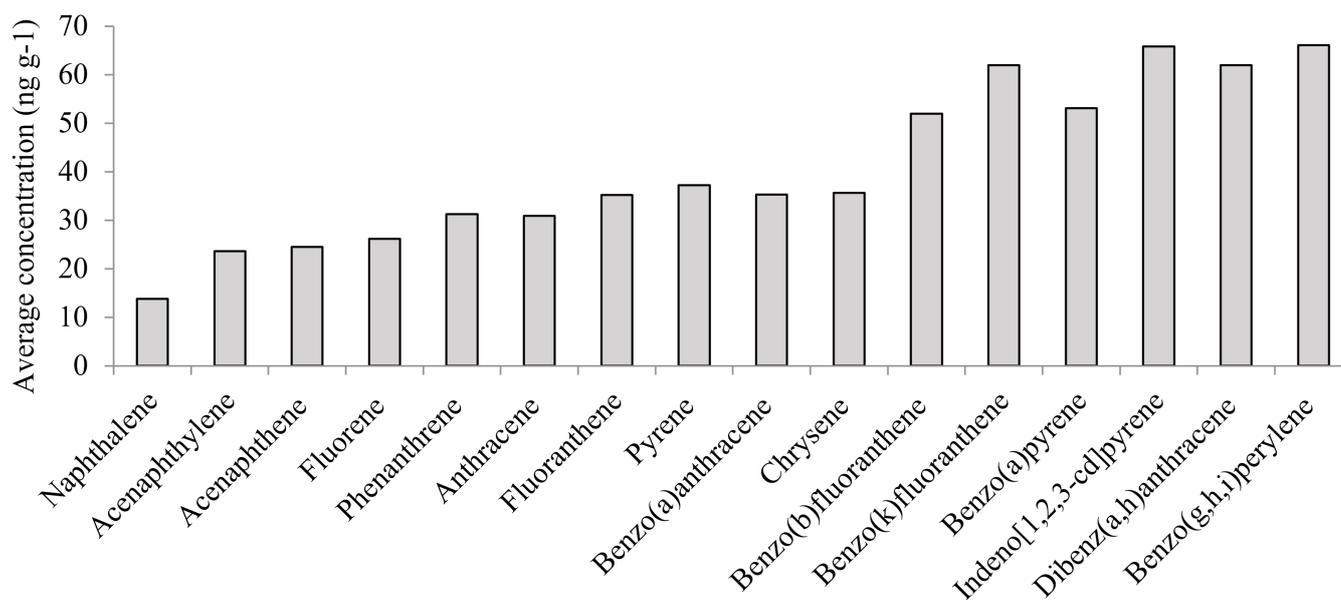


Fig. 1. Average Concentration (ng g<sup>-1</sup>) of PAHs in Soil Samples at S1.

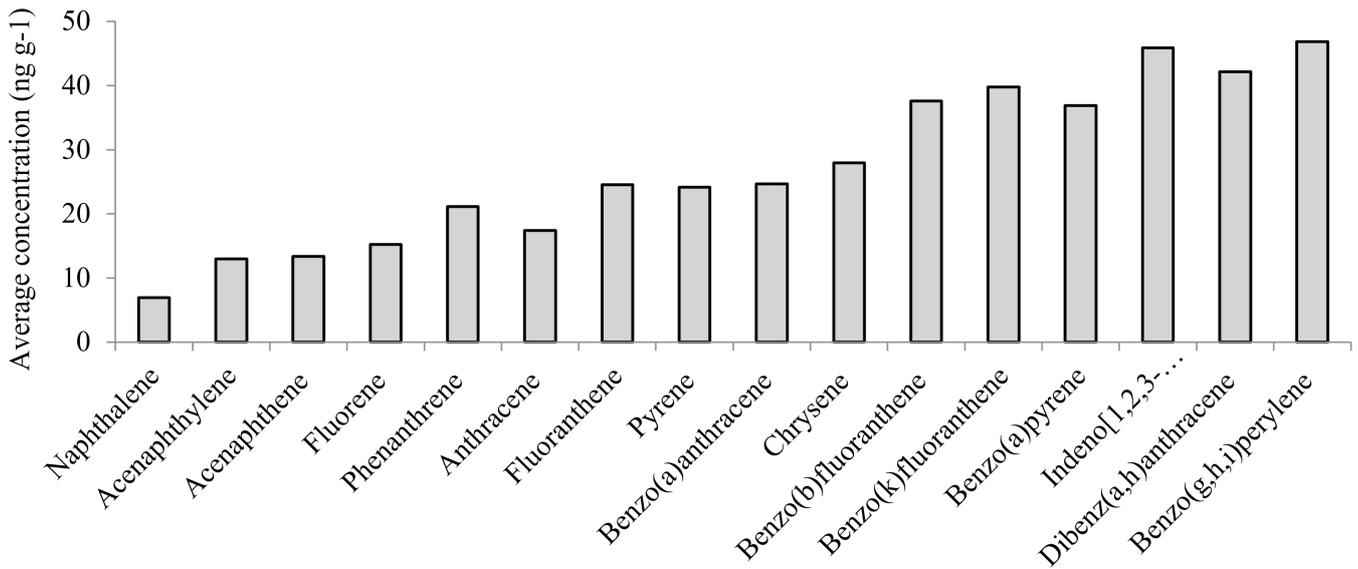


Fig. 2. Average Concentration (ng g<sup>-1</sup>) of PAHs in Soil Samples at S2.

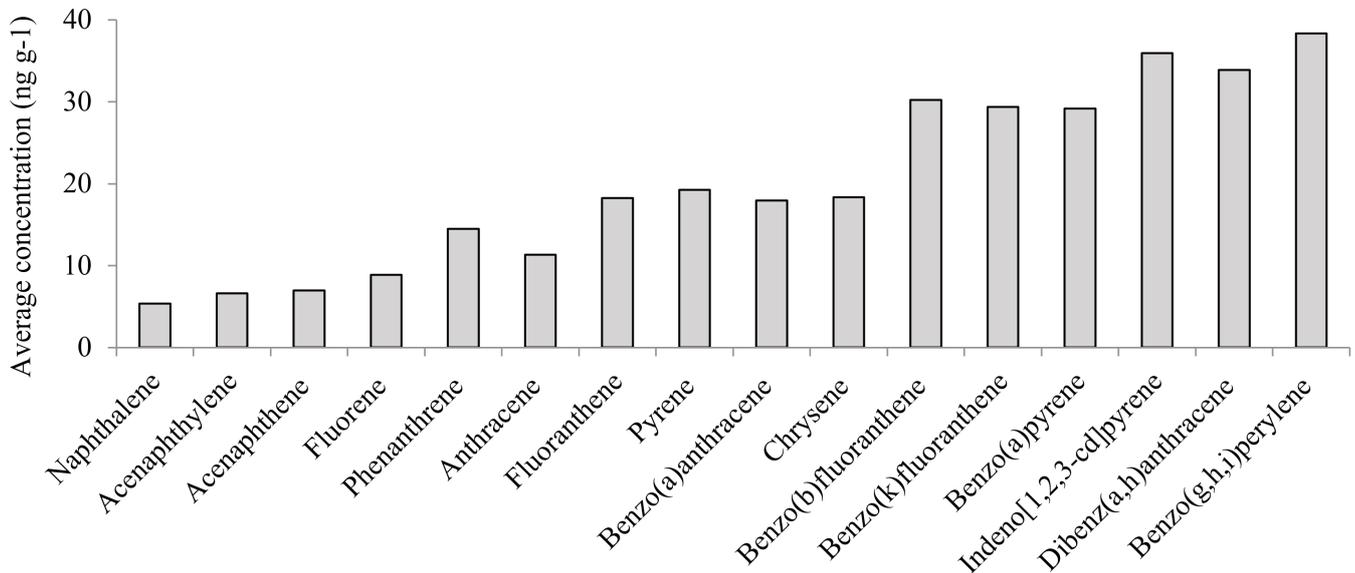


Fig. 3. Average Concentration (ng g<sup>-1</sup>) of PAHs in Soil Samples at S3.

soil samples that are collected from S1 showed the highest average total PAHs concentration (654.55 ng g<sup>-1</sup>) which is about four times higher than that corresponding to S4 (168.7 ng g<sup>-1</sup>).

Moreover, the average total PAHs concentration of soil samples collected from S3 (324.39 ng g<sup>-1</sup>) appears to be about two times higher than that of S4 (168.7 ng g<sup>-1</sup>). Because S3 is located on the edge of Tehran-Semnan road and is always jammed with motor vehicles. The obtained results are also in agreement with the similar studies in the literature [31, 32]. Several studies have investigated PAHs contamination in soil samples. Trapido [33] reported a total concentration of 16 PAHs from 2580 to 22200 ng g<sup>-1</sup> in soil samples which were collected in the vicinity of the industrial site.

Nadal et al. [1] also reported 1002 ng g<sup>-1</sup> as an average concentration of total PAHs in the soil samples collected near an industrial site. Chen et al. [34] found a total concentration of 16 PAHs ranged from 331 to 15799 ng g<sup>-1</sup> at Urumqi,

China. Nganje et al. [35] studied PAHs concentrations in the industrial sites in Calabar, Nigeria and the obtained results showed that total concentration of 16 PAHs varied from 1800 to 334430 ng g<sup>-1</sup> with an average of 50310 ng g<sup>-1</sup>. The PAHs concentrations in industrial sites in the current study (S1 and S2) are relatively lower in comparison to those reported in the literature. It can be attributed to the type of combustion processes and also the application of filters in the mentioned industrial sites in order to control and reduce PAHs emission. Trapido [33] also found total concentrations of PAHs in the range of 79 ng g<sup>-1</sup> to 385 ng g<sup>-1</sup> in rural site. Cao et al. [36] also reported 388 ng g<sup>-1</sup> as an average concentration of total 16 PAHs in the soil samples in a rural site. Peng et al. [37] investigated PAHs soil contamination at suburban and rural sites in Liaoning, China and reported the average concentration of 321.8 ng g<sup>-1</sup> and 233.5 ng g<sup>-1</sup>, respectively for suburban and rural sites. Figure 4 shows that PAHs concentrations in a rural site in this research (S4) are

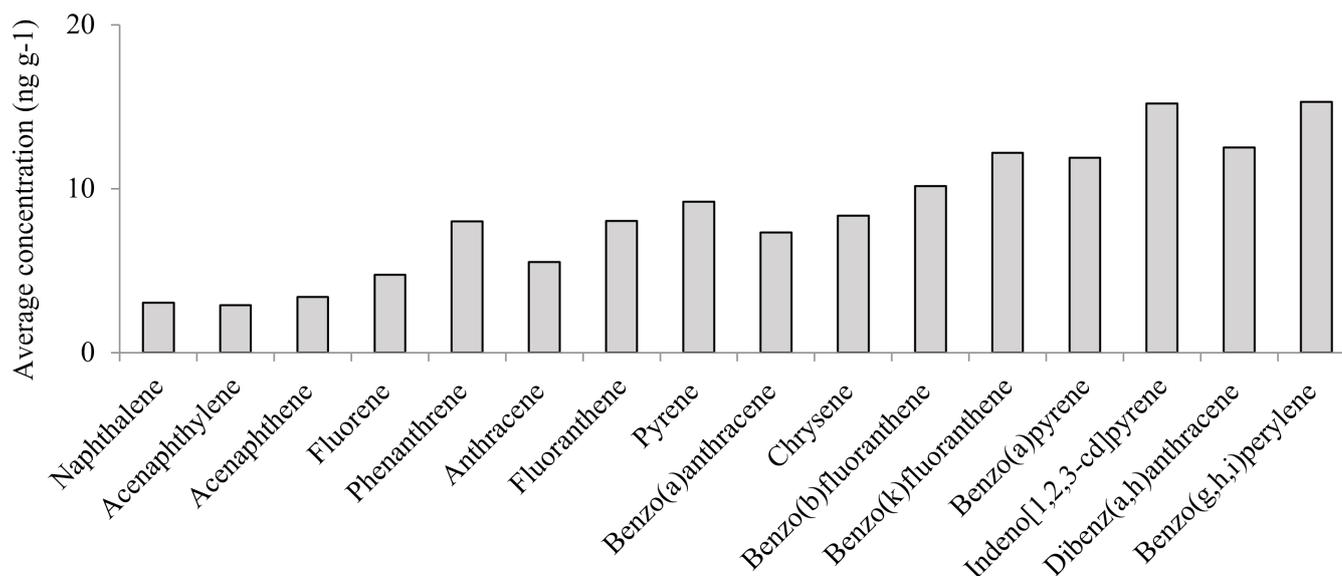


Fig. 4. Average Concentration (ng g<sup>-1</sup>) of PAHs in Soil Samples at S4.

significantly lower than those reported in the literature. It should be noted that there are no significant sources of PAHs in the vicinity of S4 and the relatively low concentration of PAHs on this site is related to predominant wind in this area which blows from the northwest to the southeast and transport PAHs compounds from PAHs contaminated area to S4. The PAHs components can be divided into low molecular weight PAHs (LMW-PAHs) with two and three aromatic rings, medium molecular weight PAHs (MMW-PAHs) with four aromatic rings, and also high molecular weight PAHs (HMW-PAHs) with five and six aromatic rings [38, 39].

The compositional profiles of PAHs in soil at each sampling site were presented in Figure 5. It indicates that HMW-PAHs were abundant at all sampling sites (which averagely accounted for 25.75% and 31.5% of total PAHs in soil, respectively for 5 and 6 rings PAHs) because HMW-PAHs have a relatively high molecular weight and also low vapor pressure, thereby HMW-PAHs can fall down and be accumulated easily near those points in which they are emitted [40]. Furthermore, LMW-PAHs had low concentrations in studied sampling sites which only accounted for 20% of total PAHs in soils. Several processes are involved in degradation of PAHs but photolysis, biotic, and also abiotic degradation are considered as main processes PAHs' degradation [21, 41]. These processes and consequently related degradation are more emphasized in LMW-PAHs mainly due to their physical and chemical properties (including low molecular weight and high vapor pressure). It has been also proved that volatilization is another main process in the global degradation of PAHs, especially in LMW-PAHs in comparison to HMW-PAHs [42]. The previous study by Cousins and Jones [43] also revealed that soils which are exposed to air experienced significant losses of lower molecular weight PAHs.

It should be noted that the studied area has warm and dry weather, especially during spring and summer. It should be mentioned that the weather condition of the studied area especially in S3 and S4 emphasizes volatilization processes. Therefore, this process can be considered as the main process responsible for the relatively low concentration of LMW-PAHs in the studied soil samples. As summarized in Table 3, four

different classes of PAHs soil contamination were suggested by Maliszewska-Kordybach [44]. This classification is based on the investigation of PAHs concentrations in the soils and human exposure risks [45].

Table 3. Classification of Soil Contamination by PAHs [44]

Class of soil contamination	Total 16 PAHs (ng g <sup>-1</sup> )
Not contaminated	<200
Weakly contaminated	200–600
Contaminated	600–1000
Heavily contaminated	>1000

The results suggest that S1 and S2 are below the range of “heavily contaminated” threshold (1000 ng g<sup>-1</sup>). The S1 with total PAH concentration of 654.55 ng g<sup>-1</sup> can be classified as contaminated. The relatively high total PAHs concentration in S1 is attributed to the vicinity of this site to the cement production company in this area which is well known as one of pollutant industries in Iran. The S2 and S3 can be classified as “weakly contaminated” with total PAHs concentration of 437.68 ng g<sup>-1</sup> and 324.39 ng g<sup>-1</sup>, respectively. Thus, not only S1 and S2 but also S3 was contaminated with PAHs which is the result of the proximity of S3 to Tehran-Semnan road that has very intense vehicles traffic.

Since there are no significant sources of PAHs in the vicinity of S4 and total PAHs concentration in this site is less than 200 ng g<sup>-1</sup>, this site can be considered as “not contaminated” based on the classification of soil contamination by PAHs. Several environmental standards (criteria or guidance) for PAHs in soil were proposed by different references such as Canadian Council of Ministers of the Environment [46], British Columbia Ministry of Environment, Lands and Parks [47], and the Ontario Ministry of Environment and Energy [48], to assess risk at contaminated sites, and monitor remediation efforts (as shown in Table 4). The total PAHs concentrations in all studied sites are under these limits. However, such environmental standards for PAHs in soil are not established yet in many developing countries, including Iran.

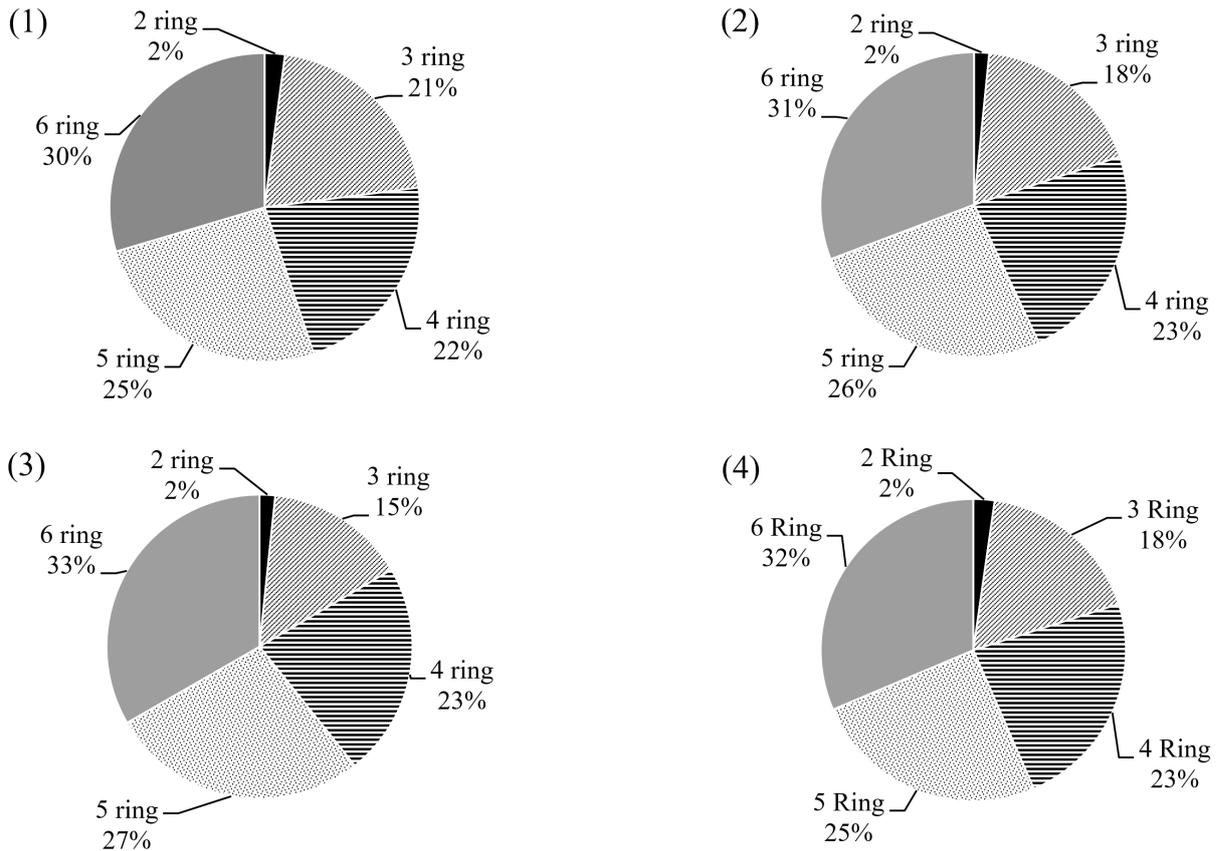


Fig. 5. The Distribution of PAHs with Different Ring Numbers in (1): S1, (2): S2, (3): S3, and (4): S4

Table 4. Some Published Soil Environmental Standards for PAHs in Soils (ng g<sup>-1</sup>)

PAHs compound	BCME R1	BCME C2	CCME AG3	CCME RP4	CCME I5	OMEE RP6	OMEE IC7
Acenaphthene						15000	15000
Acenaphthylene						100000	100000
Anthracene						28000	28000
Benzo(a)anthracene	1000	10000	100	1000	10000	6600	6600
Benzo(a)pyrene	1000	10000	100	700	700	1200	1900
Benzo(b)fluoranthene	1000	10000	100	1000	10000	12000	12000
Benzo(g,h,i)perylene						12000	12000
Chrysene						12000	17000
Dibenz(a,h)anthracene	1000	10000	100	1000	10000	1200	1900
Fluoranthene						40000	40000
Fluorene						340000	340000
Indeno[1,2,3-cd]pyrene	1000	10000	100	1000	10000	12000	19000
Naphthalene	5000	50000	100	600	22000	4600	4600
Phenanthrene	5000	50000	100	5000	50000	40000	40000
Pyrene	10000	100000	100	10000	100000	250000	250000

<sup>1</sup>BCME R: British Columbia Residential; <sup>2</sup>BCME C: British Columbia Commercial; <sup>3</sup>CCME AG: Canadian Council of Ministers of the Environment Agricultural; <sup>4</sup>CCME RP: Canadian Council of Ministers of the Environment Residential/Parkland; <sup>5</sup>CCME I: Canadian Council of Ministers of the Environment Industrial; <sup>6</sup>OMEE RP: Ontario Residential/Parkland land use (coarse- Ag/g); <sup>7</sup>OMEE IC: Ontario Industrial/Commercial land use (coarse Ag/g).

#### 4- Environmental health risk assessment

The assessment of health risk due to exposure to PAHs is generally based on concentrations of PAHs and the use of epidemiological results. The environmental risk assessment associated with PAHs is often estimated in terms of benzo (a)

pyrene (BaP) concentration because of the high carcinogenic potency of BaP. It should be mentioned BaP is one of carcinogenic PAHs compounds in a mixture of carcinogens present in the environment and people are unlikely to be exposed to a single PAH compound. Hence, BaP approach

ignores the effects of other PAHs on the assessment of health risk and thereby provides an inefficient evaluation of the risk of PAHs. The development and establishment of Toxic Equivalency Factors (TEFs) for PAHs is a comprehensive approach which overcomes the shortcomings of BaP approach in the assessment of health risk due to the exposure to PAHs. TEFs compare relative toxicity of individual PAHs to BaP. The determined concentrations of individual PAHs are converted to the BaP equivalents (BaPeq) concentrations and thereby TEF of 1 is given to BaP.

Sixteen EPA priority and seven carcinogenic PAHs concentrations in the studied soil samples in terms of ng BaP eq/g are summarized in Figure 6. It should be noted that TEF values for PAHs components were derived from Hester [49] and Nisbet and LaGoy [50]. The obtained results indicated that S1 has the maximum and S4 has the minimum total PAHs concentration based on BaP equivalents among the studied sites. Moreover, the derived results imply that there is no significant difference in TEFs for 7 carcinogenic PAHs in comparison to 16 EPA priority PAHs. This can be attributed to the relatively high TEFs for the studied carcinogenic PAHs in the current study [1]. Nadal et al. [1] also reported the similar results for PAHs concentration in soil samples from Tarragona County, Spain.

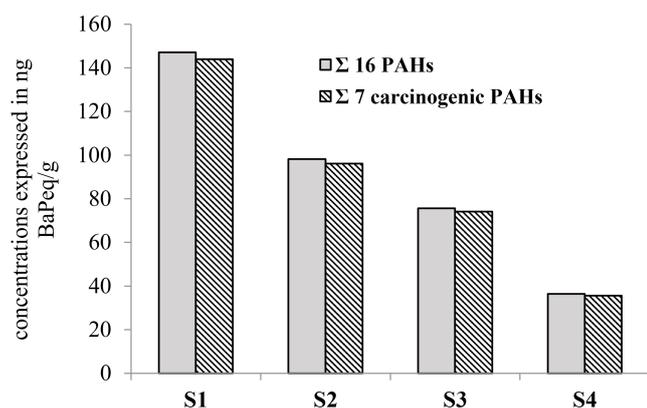


Fig. 6. Sixteen EPA Priority and Seven Carcinogenic PAHs Concentrations in Soils (expressed in ng BaP<sub>eq</sub>/g).

## 5- PAHs Sources

Identifying and determining the sources of PAHs can make a significant contribution to comprehensive understanding transport and the fate of PAHs in the environment. The anthropogenic PAHs can originate from pyrogenic and petrogenic sources. Previous studies reported that PAHs compositions and ratios can be used to discriminate PAHs sources to natural and anthropogenic ones [51-54]. These indices lie on the fact that PAHs distribution is influenced by temperature [55]. During high-temperature processes, the PAHs distribution is mainly governed by kinetic characteristics while the PAHs distribution is mainly governed by thermodynamic properties during low-temperature processes [55].

Baumard et al. [56] suggested the ratios of fluoranthene/pyrene (Flu/Pyr) within the four ring PAHs group and phenanthrene/anthracene (Phe/Ant) within the 3 ring PAHs group can be used as molecular indices for the discrimination of the origins of PAHs.

At low-temperature process, produced a molar fraction of

phenanthrene is higher than that of anthracene because of the fact that Phenanthrene is more thermochemically stable than anthracene. Therefore high-temperature processes are recognized by low Phe/Ant ratio values.

The discrimination of the origins of PAHs can also be evaluated based on the value of Flu/Pyr. Moreover, the different ratios of molecular indices can be relevant to the degree of photo degradation, biodegradation, and grain size distribution of samples [57]. A Phe/Ant ratio less than 10 and Flu/Pyr ratio more than 1 indicates that PAHs contamination is the results of combustion processes [58]. It should be noted that both ratios should be considered simultaneously in order to provide an appropriate estimation of PAHs sources [59]. Tam et al. [57] observed soil samples with Phe/Ant ratio more than 10 and Flu/Pyr ratio less than 1 had a petrogenic origin, while samples with Phe/Ant less than 10 and Flu/Pyr less than 1 were characterized by mixed pyrolytic and petrogenic sources. The different ratios can be related to the degree of PAHs photo degradation or biodegradation and also to the grain size distribution of the soil samples [57].

In the current study, the Flu/Pyr ratios in all samples ranged from 0.49 to 1.46 and Phe/Ant ratios ranged from 0.87 to 2.28. According to the ratios of Phe/Ant versus Flu/Pyr presented in Figure 7, it can be concluded that the studied soil samples were contaminated by both pyrolytic and petrogenic sources. This could be explained by a presence of complex sources of PAHs in the studied sampling sites which can contribute to PAHs contamination in soils.

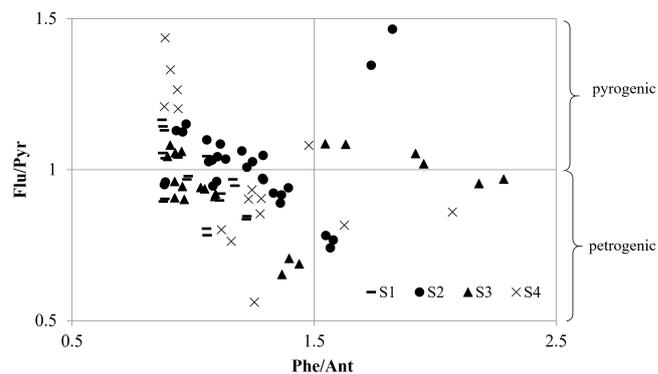


Fig. 7. The Ratios of Phe/Ant Versus Flu/Pyr in Analyzed Soil Samples.

## 6- Conclusion

In this paper, contaminations of 16 PAHs in the soil the samples from four sampling sites along Tehran-Semnan road were evaluated. The results demonstrated that PAHs are ubiquitous contaminants in the currently studied area due to the heavy industrial and vehicle traffic activities. The studied soil samples were contaminated by PAHs ranging from 148.4 ng g<sup>-1</sup> to 721 ng g<sup>-1</sup>. Compared to other similar sites in the literature, all investigated sites along Tehran-Semnan road are contaminated to a moderate degree by PAHs. The profile of PAHs indicated that 5-6 ring PAHs were predominated contamination in comparison of 2-3 ring PAHs in all sampling sites. Tracking analysis conducted by evaluating the ratios of Flu/Pyr and Phe/Ant revealed that PAHs contamination in the studied sites were caused by both of pyrolytic and petrogenic sources. TEFs were also used to assess potential ecosystem risk of PAHs in the soils. Results indicated that ecosystem risk

of PAHs was relatively low to moderate in studied sampling sites along Tehran-Semnan road. The results of this study can be used for future assessment of PAHs contamination and also they indicate that some remedial actions and control measures should be performed in order to decrease the PAHs contamination in the investigated areas.

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